NASA SBIR 2022 Phase I Solicitation

Z4.07 Advanced Materials and Manufacturing for In-Space Operations

Lead Center: LaRC

Participating Center(s): MSFC

Scope Title

Manufacturing of Materials from Lunar Surface Resources

Scope Description

As humanity embarks on sustained deep space exploration, starting with the lunar surface, there will be a need for building infrastructure that is based on indigenous resources [1]. Usage of these resources will face limitations that include the available source materials, equipment, and power. Therefore, materials processing and manufacturing approaches are required that are operable within these constraints.

Operations on the lunar surface must consider types of materials available as well as their abundance. Various in situ resource utilization (ISRU) efforts are ongoing to extract and process the raw materials into usable forms. These include some SBIR topics that the prospective proposer is encouraged to look into. Elements available for extraction from regolith include oxygen, silicon, iron, calcium, aluminum, magnesium, and titanium. From these, and from other materials that may be available in smaller quantities, manufacturing methods are needed to produce components for construction and for the building, replication, and repair of equipment.

Proposals are invited for approaches that utilize the resources available on the Moon in order to be able to produce structural girders, beams, and pipes that can withstand both tensile and bending forces. These are required in addition to compacted cementitious and sintered materials that can carry mostly compressive loads.

Concepts can include, but are not limited to, production using various metallic materials as well as basalt-fiber-reinforced geopolymers and other combinations that can be produced from lunar resources. Manufacturing methods that capitalize on the lunar environment are of particular interest.

The selection of the material system must take into account the potential availability on the lunar surface and a demonstrated or projected ability to support tensile and bending loads. For example, proposed work may include an analysis of lunar material properties and processing methods that yield the required performance characteristics for relevant structures. An example beam would be a structural component for a crane with a 25-ft reach that can support one metric ton (2,200 lb) in lunar gravity. Proposers are pointed to the references provided [2-6] as well as ongoing ISRU activities for the latest and detailed information on the potential availability of various materials on the Moon.

Proposals to the current solicitation can assume the materials extracted and processed in the ISRU activities to be available and ready to use at levels of purity that range from as-dug regolith to separated and refined metals. The quantities available will depend on the lunar abundance of the materials and the effort needed for the processing. As-dug regolith can be expected to be available in large amounts; more refined materials can be expected to be available in quantities that decrease with the level of refinement and the requirements for that refinement, such as energy and any Earth-sourced ingredients.

Proposal elements of interest include but are not limited to:

- Material concepts that can utilize various purities of feedstocks, e.g., concepts that might be able to use a metal at less than 100% purity.
- Manufacturing processes that can take advantage of the lunar environment, such as vacuum, radiation, reduced gravity, etc.
- Equipment required for the manufacturing, including the size scale, power requirements, production rates, and operating environments.
- Preliminary proof-of-concept experiments for feasibility of the proposed material systems, processing methods, and equipment.

Expected TRL or TRL Range at completion of the Project

4 to 5

Primary Technology Taxonomy

Level 1

TX 12 Materials, Structures, Mechanical Systems, and Manufacturing

Level 2

TX 12.X Other Manufacturing, Materials, and Structures

Desired Deliverables of Phase I and Phase II

- Research
- Analysis
- Prototype
- Hardware

Desired Deliverables Description

Phase I: Define the material system to be used for manufacturing of relevant components, the processes required, and the equipment needed to process that material. Provide one or more material systems, manufacturing processes, and equipment design concepts for the production of tensile- and bending-force-supporting components on the lunar surface using resources available from ISRU extraction and beneficiation activities. The concept will include analysis of how the material system(s) is/are able to meet the load-carrying requirements and the manufacturing parameters, and how the equipment that is required utilizes/succeeds in operating in the lunar environment.

Phase II would look at scaled/laboratory demonstrations of the material system(s), manufacturing processes, and equipment. These would include designing and building of relevant equipment and potential processing of commercially available regolith simulants or other materials that may match the materials expected to be available on the Moon, either in raw form or from other processes. Test coupons must be built and tested using as close an analog as possible of the lunar material system and a prototype of the proposed manufacturing equipment. Documentation of requirements for the manufacturing process and operation of the equipment, such as power and mass that can be used to evaluate feasibility in trade studies, shall be included.

State of the Art and Critical Gaps

Sustainable long-term exploration of the Moon will be dependent on the utilization of lunar resources. While various efforts are looking at the excavation and extraction of those resources, there are currently gaps in manufacturing of the material feedstocks that may be available on the Moon into other useful products. Addressing these gaps requires understanding of the fabrication equipment and the full manufacturing cycle as well as the expected impact when the processes are run on the Moon.

Relevance / Science Traceability

The Artemis program envisions the start of a long-term human presence on the lunar surface for the exploration and development of the Moon by Government as well as commercial companies and international partners. In order to support these missions, it will be essential to utilize resources that can be sourced from the lunar surface. The current solicitation calls for proposals that provide the support for these exploration and development activities. Technologies that are developed in this solicitation may also feature on preparatory missions for Artemis, such as the Commercial Lunar Payload Services Programs, depending on the readiness of the technology.

References

1. NASAâ€™s Plan for Sustained Lunar Exploration and Development. https://www.nasa.gov/sites/default/files/atoms/files/a_sustained_lunar_presence_nspc_report4220final.pdf [accessed 07/23/2021].
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3. R. D. Waldron. Lunar Manufacturing: A Survey of Products and Processes. Acta Astronautica. 1988; 17(7):691-708.
4. Dave Dietzler. Making It on the Moon: Bootstrapping Lunar Industry. NSS Space Settlement Journal, September 2016. https://space.nss.org/wp-content/uploads/NSS-JOURNAL-Bootstrapping-Lunar-Industry-2016.pdf [accessed 07/22/21].
5. I. A. Crawford. Lunar Resources: A Review. Progress in Physical Geography: Earth and Environment. 2015; 39(2):137-167.
6. United States Geological Survey (USGS). Unified Geologic Map of the Moon. https://astrogeology.usgs.gov/search/map/Moon/Geology/Unified_Geologic_Map_of_the_Moon_GIS_v2 [accessed 07/23/2021].

Scope Title

Welding Testbed for Space Manufacturing

Scope Description

Technology development efforts are required to enable on-orbit servicing, assembly, and manufacturing (OSAM) for commercial satellites, robotic science, and human exploration. OSAM is an emerging national initiative to transform the way we design, build, and operate in space. The goal of the initiative is to develop a strategic framework to enable robotic servicing, repair, assembly, manufacturing, and inspection of space assets.

An in-space material welding capability is an important supporting technology for the long-duration, long-endurance space missions that NASA will undertake beyond the International Space Station (ISS). Historically, structures in space have been assembled using mechanical fastening techniques and modular assembly. Structural designs for crewed habitats, space telescopes, antennas, and solar array reflectors are primarily driven by launch considerations such as payload fairing dimensions and vibrational loads experienced during ascent. An in-space welding capability will greatly reduce constraints on the system imposed by launch, enabling the construction of larger, more complex, and more optimized structures. Welding is an essential complementary capability to large-scale additive manufacturing technologies being developed by NASA and commercial partners. Welding is also a critical capability for repair scenarios (e.g., repair of damage to a structure from micrometeorite impacts).

The development of welding processes for a variety of materials and thicknesses is carried out via a welding destructive testing and nondestructive testing feedback loop. This ensures that a weld procedure is well understood and that it produces welds that have sufficient material properties for their end-use application. While weld procedures are developed on the ground in simulated space environments, it is also necessary to further develop and validate these procedures in the true space environment where they will be applied. To achieve this need, a fully autonomous welding testbed must be created and deployed in space.

This subtopic seeks innovative engineering solutionsâ€”both fully autonomous and semiautonomousâ€”to robotically weld materials for manufacturing in the unpressurized space environment. Current state-of-the-art (SOA) terrestrial welding methods such as laser beam, electron beam, and friction stir should be modified with an effort to reduce the footprint, mass, and power requirements for on-orbit applications.

Targeted applications for this technology include joining and repair of components at the subsystem level, habitat modules, trusses, solar arrays, and/or antenna reflectors. The need to repair a damaged structure or build new structures may require the need to not only weld material but to cut and remove material. A process that can weld material is the priority, but a robust process with cutting, removal, and testing capabilities adds value.

Expected TRL or TRL Range at completion of the Project

3 to 6

Primary Technology Taxonomy

Level 1

TX 12 Materials, Structures, Mechanical Systems, and Manufacturing

Level 2

TX 12.4 Manufacturing

Desired Deliverables of Phase I and Phase II

- Research
- Analysis
- Prototype
- Hardware
- Software

Desired Deliverables Description

Phase I is a feasibility study and laboratory proof of concept of a robotic welding process and system for on-orbit manufacturing applications. The Phase I effort should provide a laboratory demonstration of the welding process and its applicability to aerospace-grade metallic materials and/or thermoplastics, focusing on joint configurations that represent the priority in-space joining applications identified above. Work under Phase I will inform preliminary design of a mobile welding unit and/or in-space welding testbed. It will also inform a concept of operations for how the system would be deployed and operate in the space environment, with a focus on specific scenariosâ€”for example, repair of a metal panel following micrometeorite damage, longitudinal welding of two metal curved panels, and welding of a truss to an adjacent truss. The Phase I effort should also provide an assessment of the proposed process operational capabilities (e.g., classes of materials that can be welded with the process, joint configurations that can be accommodated, and any expected impacts of the microgravity environment on joint efficiency relative to terrestrial system operation), volume, and power budget. A preliminary design and concept of operations are also deliverables under Phase I. Concepts for ancillary technologies such as postprocess inspection, in situ monitoring, mechanical testing, or robotic arms for manipulation of structures to be welded may also be included in the Phase I effort.

Development of a prototype with detailed analysis, initial testing, and associated software is desired for Phase I.

Phase II should further develop the prototype from Phase I and provide substantial test data using the prototype in an environment similar to the end application.

State of the Art and Critical Gaps

A clear demonstrated understanding of the SOA is required. Any proposed technologies should not replicate the SOA and should instead advance the SOA or create an entirely different approach from the SOA. Welding in space has a multitude of applications, from repair to manufacturing, and is necessary to ensure a sustainable human presence in space. The development of space welding technologies is a substantial undertaking and requires years to perfect, so it is of the utmost importance that this process begins now. A welding testbed in space is an integral part of gaining weld property feedback data in an autonomous manner in a high-fidelity environment. The current SOA requires further advancement, and the growth of small business in the field of space welding is the best route to ensure that technological development is unique and that an array of technology providers exists in the future space economy.

Relevance / Science Traceability

Space welding is necessary for the future sustainability of the space economy. To both build and repair structures in space, on the lunar surface, or on Mars, welding is a valuable tool that will provide agility for astronauts in a location where resources are highly limited. The development of space welding is a significant undertaking, so early development must begin now. The development of systems to autonomously weld structures in space and the ability to develop welding parameters through a closed-feedback-loop space testbed are both required to ensure that welding may be sufficiently applied in space.

References

1. Tracie Prater et al. Overview of the In-Space Manufacturing Technology Portfolio. 2019. https://ntrs.nasa.gov/api/citations/20190030353/downloads/20190030353.pdf
2. Leigh M. Elrod et al. ISM In-Space Manufacturing. 2019.https://ntrs.nasa.gov/citations/20190033503